Volume 20 February, 1934 *Number 2*

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Plain Bearing Design, Construction and Composition

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

about bearing protection

● Bearing lubrication is a subject of extreme importance, because of its direct relation to operating efficiency. Where the problems of lubrication have received careful study and where operating conditions and their effect on lubricants in general have been analyzed by the bearing designer, the manufacturer, and the operating engineer, maximum bearing efficiency will naturally follow.

● Maintenance of a protective lubricating film in any plain or sleeve type bearing requires continuous delivery of the necessary amount of lubricant to furnish the film, and suitable bearing construction to permit of even distribution throughout the clearance space.

● Design and construction are most important in the attainment of effective bearing lubrication. Research has developed certain fundamental laws, but practical experience and thorough understanding of the materials involved in bearing construction are essential to the successful application of these laws.

● The information in the accompanying article on plain bearing design and lubrication is practical and substantiated by actual experience. It is presented with the hope that it will be of equal interest to the research student, the bearing designer, the machinery builder, and the operating engineer.

THE TEXAS COMPANY
Texaco Petroleum Products

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Published by

The Texas Company, 135 East 42nd Street, New York City

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Vol. XX February, 1934 No. 2

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Plain Bearing Design, Construction and Composition

IN machine design bearings constitute the supporting or carrying elements for shafting, journals, or pins according to the type of machinery involved. As such they are subjected to contact with sliding or rotating elements. Actual metallic contact would lead to serious difficulties due to friction, abnormal rise in temperature, and the subsequent possibility of melting of the bearing metal, which would cause the shaft or other moving element to drop or seize. This is prevented and continued operation is assured by maintenance of a film of lubricant between the surfaces of the bearing and its component moving part. This amounts to substitution of fluid friction for solid friction.

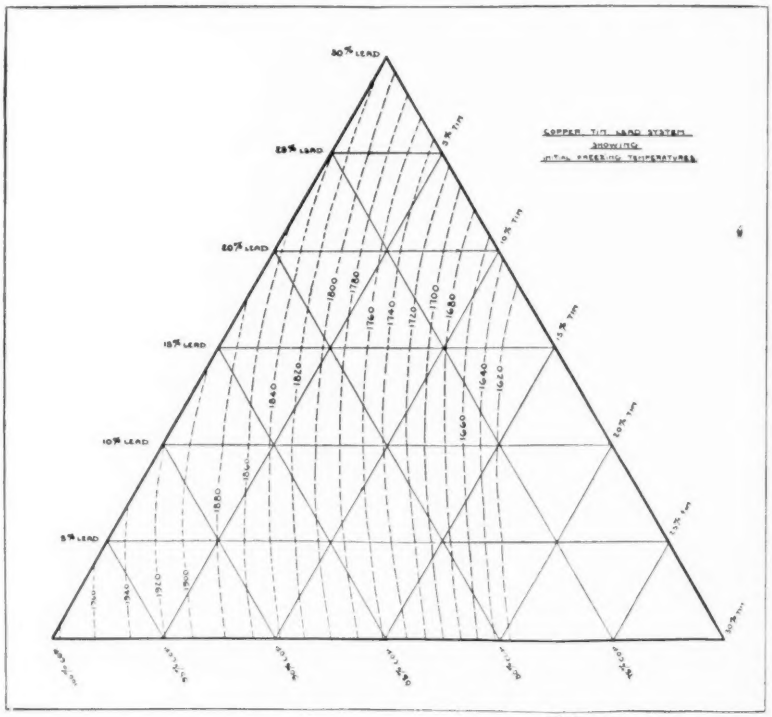
In the plain or sleeve type bearing, study of lubricant characteristics, composition of bearing metals and methods of lubrication is essential to effective bearing protection. This is assured by positive lubrication through continuous delivery of the necessary amount of lubricant to furnish an adequate film, and suitable bearing construction to permit of complete circulation of the lubricant throughout the clearance space, which exists between the stationary and moving parts.

The plain or sleeve type bearing has become so vital a part in the design of steam turbines, Diesel engines, reciprocating steam units, the automotive engine, and certain types of industrial machinery as to warrant expectation that it will probably never be supplanted by any more efficient device. With continued improvements in methods of lubrication it is becoming even more firmly established as an adjunct to dependable operation of such equipment. This is further enhanced by study of bearing design in order to assure proper location of oil grooves, and beveling or chamfering of all joints or breaks in the bearing surface. No bearing should be cut-away or have the continuity of its surface altered by grooves within thirty degrees either way of the point of maximum pressure; otherwise uniformity in the oil film may be impaired. In some bearings it may even be advisable to increase this figure to sixty degrees, according to clearance and speed conditions. By this same premise the lubricant should wherever possible be led into the bearing at the point where pressure is lowest and where wedge action via chamfering can be employed to aid in film formation.

Investigations into the theory of lubrication have proved that a definite relation exists between load, operating speed, bearing clearance, viscosity of the lubricant and point of oil application. The theory of lubrication has long been a popular subject for research and discussion among scientists who have interested themselves in oil film development and behavior. Most recently these studies have been directed towards adaptation of accepted theories to practical solution of problems which

are of direct interest to designing and operating engineers. These studies have indicated that selection of an oil of the estimated proper viscosity, based on past practical experience, can be extended and checked to determine the degree to which practice agrees with theory. In this way correction can be made of any error in original selection of the oil, so that a product best suited to the operating conditions can be obtained, capable of producing the lowest coefficient of friction for any given combination of speed, clearance and load.

Bearing construction, of course, has a direct relationship to the above. Bearing metals in particular must be thoroughly understood, for they, in company with lubrication, constitute the boundary between success and failure in machine operation. When lubrication is effective and an adequate film is constantly maintained the bearing serves chiefly as a guide to insure alignment; in event of failure of the lubricating film, however, it devolves upon the bearing to function as a safeguard to prevent actual damage to shafting or other parts of the machine. For this reason bearing metals must be softer than any of the steels used for shafting or journal construction, and capable of wiping or even melting when in actual rubbing contact with the latter, to insure against scoring or cutting. To assure of the highest degree of protection for the rotating or sliding elements, as a counterpart of positive lubrication, the bearing in service must show a low coefficient of friction, with ability to assist in maintenance of a lubricating film especially under adverse conditions.



Courtesy of Federal-Mogul Corporation

Fig. 1—Chart showing initial freezing temperature for copper-tin-lead alloys. Temperatures are shown by curved, dotted lines, in degrees Fahrenheit. When desirable to determine the freezing point of an alloy containing zinc in addition to the above metals not in excess of 5%, zinc and tin contents are added together and used on the chart as representing the tin percentage.

It must be of sufficient hardness to carry the prevailing loads even at abnormally high temperatures, without wiping or becoming distorted, and yet the metal must be sufficiently plastic or ductile to conform to any irregularities on the surface of the shaft. To enable ready handling and proper forming it must pour easily and maintain a uniform alloy structure throughout the body of the material. In this regard, the extent to which a bearing can be expected to function effectively in service will depend upon its initial formation, including the manner in which it has been poured or cast, the temperature of pouring and the precautions observed in heating the bearing shell or mold. The pouring temperature will be contingent upon the type of bearing metal, its base and the relative percentages of the metals which comprise the alloy. Average pouring temperatures for babbitts will range from 600 to 900 degrees Fahr. The bronzes however, will range up to 2300 Fahr. Manufacturers' specifications should be closely followed in deciding upon the pouring temperature.

TYPES OF BEARING METAL

Bearing metals with respect to their base have been discussed by the A. W. Cadman Manufacturing Company.* Their opinions are quoted below:

"All modern soft metal bearing linings consist essentially of either tin, lead or zinc, with the addition of some other element, or elements, to give them the requisite strength and hardness."

"Tin-Base Metals

"The true tin-base metal contains from 80 to 92 per cent of tin, 3 to 10 per cent of copper,

* Bearings and Bearing Metals, Engineering Bulletin M2. A. W. Cadman Manufacturing Company.

and 5 to 10 per cent of antimony. Some authorities claim that the addition of up to 5 per cent of lead improves the physical and bearing properties of the metal. There is, however, no good evidence to support this claim, and much to refute it. Nickel is also sometimes added to the tin-base metals in small quantities for its hardening influence, but there is no question that the hardening in this case is obtained at the sacrifice of more important bearing properties and there can be no justification for its use."

"The tin-base babbitts are, as a rule, harder than the lead-base metals. The tin-base metals have greater toughness and tensile strength. They are very fluid in the molten condition, and can therefore be cast into very thin sections. They sweat readily to the supporting shell or box."

"The tin-base metals are unequalled for use in bearings which are subjected to a constant pounding action."

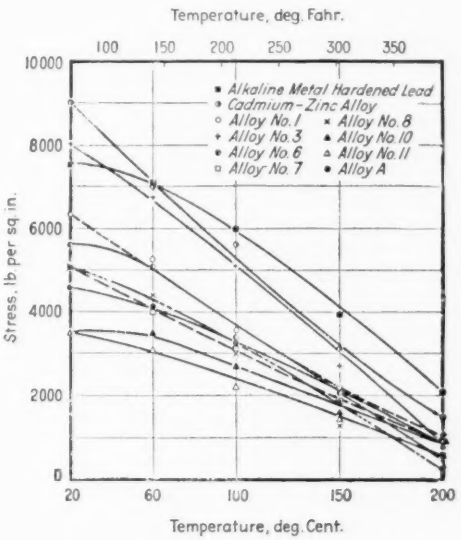
"Lead-Base Metals

"Lead-base metals contain from 70 to 90 per cent of lead, 9 to 20 per cent of antimony, and 0.5 to 9 per cent of tin. They may also contain small percentages of copper. It is, however, difficult to add a proportion of copper greater than 5 per cent of the tin content, unless special precautions are taken both in the original alloying and the subsequent remelting."

"Lead-base metals have, normally, fair hardness and compressive strength, low tensile strength and elongation. They have the advantage of unequalled self-lubricating qualities and low first cost."

"Lead-Tin Alloys

"The lead-tin alloys are at best a substitute for the tin-base metals, with the only advantage of reduced cost. The addition of tin to a lead-base metal increases its hardness without decreasing its toughness to the same extent as antimony. Alloys containing more than 20 per cent of tin are both harder and tougher than the usual lead-base metals, but the relative wear is greater than in either the tin or lead-base metals."



Courtesy of American Society for Testing Materials and Bureau of Standards, U. S. Department of Commerce.

Fig. 2—Showing relation of compression stress to temperature of test from a paper by H. K. Herschman and J. L. Basil dealing with mechanical properties of white metal bearing alloys at different temperatures. For alloy contents see Table No. 1.

TABLE I.—RESULTS OF CHEMICAL ANALYSES OF WHITE-METAL BEARING ALLOYS.

Alloy	Lead, per cent	Tin, per cent	Antimony, per cent	Copper, per cent	Cadmium, per cent	Zinc, per cent	Other Constituents, per cent
No. 1	....	90.9	4.6	4.5	....	....	....
No. 3	....	83.8	8.1	8.1	....	....	....
No. 6	62.3	20.8	15.5	1.4	....	....	....
No. 7	78.8	8.4	12.8	....	....	....	....
No. 8	79.7	5.0	15.3	....	....	....	....
No. 10	87.0	1.2	11.8	....	....	....	....
No. 11	88.1	....	11.9	....	....	....	....
Alkaline-earth metal hardened lead[a]	96.93	0.18	....	0.1	....	....	Hg, 0.33; Ba, 1.70; Ca, 0.70.
Cadmium-zinc[b]	....	....	....	....	82	18	....
A	80.6	3.8	13.5	1.0	0.2	....	Ni, 0.2; As, 0.6.

[a] Analysis made by the National Lead Co.
[b] Nominal composition

"Lead-Base Metals Containing Salts

"Lead-base metals containing very small percentages of certain chemicals, or salts, have unusual hardness and tensile strength as compared with the ordinary lead-base metals. They appear, however, to be subject to a rearrangement of the crystals which continues for months after they are poured into bearings and

COPPER BASE BRONZES*

Metal	*Average Composition*	*Relation to Lubrication*
F.1—"Admiralty Bronze" or "Gun Metal" S.A.E. Spec. 62	Copper 88% Tin 10% Zinc 2%	To be used where lubrication is very good, or motion is of a rocking nature. A good gear bronze suitable for heavily loaded piston pin bushings, or similar purposes.
F.2—80-10-10 Leaded Bronze S.A.E. Spec. 64	Copper 80% Tin 10% Lead 10%	One of the strongest and hardest of the lead bronzes. Should not be used where lubrication is poor. Where properly lubricated it is adaptable to heavy loads and severe usage.
F.3—"Ounce Metal" "Steam Metal" or "Red Brass" A.S.T.M. Spec. B, 62-28	Copper 83-86% Tin 4-6% Lead 4-6% Zinc 4-6%	In bearing field used largely as backing for babbitt lined bearings.
F.5—Known as S.A.E. No. 66 Alloy	Copper 85% Tin 5% Lead 9% Zinc 1%	Used for babbitt lined bearing backs and for bushings where service is not severe. Due to low resistance to pounding should not be used under heavy loading.
F.6—"Ex-B Metal" "Engine Brass" or "Semi-Plastic Bronze" S.A.E. Spec. 67	Copper 76-78% Tin 7-9% Lead 14-16% Zinc 0.5% Max.	Suited to average bushing applications, but requires better lubrication than metals with a higher lead content.
F.8	Copper 83% Tin 7% Lead 7% Zinc 3%	A good average bearing bronze, suited to medium loads. Lacks resistance to pounding due to low strength and hardness.
F.11—"Leaded Gun Metal" or Modified "Admiralty Bronze"	Copper 87-89% Tin 9-11% Lead 1.5-2.5% Zinc 1% Max.	A general utilities bronze adaptable to heavy loads and severe working conditions. Must be well lubricated, however, or overheating and scoring may develop. By reason of its lead content the wearing and anti-friction properties are better than straight admiralty bronze.
F.13—A modified F.1 Admiralty Bronze	Copper 86-89% Tin 9-10% Lead 1-3% Zinc .75-1.5%	Structurally similar to F.11 bearing bronze, though capable of more easy machining. In service requires same consideration as to positive lubrication as F.1 and F.11 bronzes.
F.15	Copper 70% Tin 10% Lead 20%	Suitable under adverse lubrication conditions, and moderately heavy loads, due to high lead content.
F.16—"Journal Bearing Metal"	Copper 70% Tin 5% Lead 25%	Useful where lubrication may be interrupted. Under low speeds and light loads may even function for sometime without lubrication. Soft steel shafts will not be scored should lubrication fail except under very high speeds or low clearances. Very low in resistance to shock or pounding.
F.18—A modification of F.16 "Journal Bearing Metal"	Copper 72-74% Tin 6-8% Lead 18-20% Zinc 1.5% Max.	Stronger and harder than F.16 bearing bronze. The lead content is sufficiently high to prevent scoring under impaired lubrication.
F.19—"Ford Z Metal"	Copper 85-89% Tin 7.5-8.5% Lead .75-1.5% Zinc 2.25-4.25%	A strong ductile alloy of average hardness suited to service to which other low lead compositions would be adapted.

* Bearing Metal Data, Federal Mogul Corp.

this action seems to react against their physical properties, rendering them unstable for service when subjected to water or even operating in an atmosphere heavily loaded with moisture. Under these conditions salts of calcium and sodium base are readily dissolved out of the alloy. It is possible, therefore, that their advantages are outweighed by their apparent impermanence."

"Tin-Base Metals Containing Zinc

"These metals, of which Parson's White Brass is a typical example, possess great compressive strength and are peculiarly adapted for bearings which are subjected to an extremely heavy pound, as in bolt heading machines and certain types of rock crusher."

"The white brasses require a high pouring temperature, are very sluggish and cannot be poured into thin linings. They require exceptional lubrication, or they will seize and cut the shaft. Their use should be limited to the bearings described above."

"Copper-Base Metals or Bronzes

"The copper-base metals contain from 88 to 50 per cent of copper, 10 to 5 per cent of tin, and 50 to 5 per cent of lead. They may also contain small percentages of zinc and nickel. The use of the last-named metals has objections from a bearing standpoint, and it is desirable to keep down their proportions as much as possible."

"The bronzes have, as a rule, great hardness and compressive strength, and a high melting point. As, however, their rate of wear and tendency to heat is greater than that of the white metals, their use should be confined to bearings in which their high melting point and great strength are essential."

"The bronzes, owing to their hardness, do not 'seat' readily to the journal, consequently the shaft may ride on a number of high points, and this reduction of the effective bearing area greatly increases the tendency to overheat under abnormal conditions. In many cases a hot bearing can be remedied by simply replacing the bronze with a white metal, provided the conditions will permit the use of a babbitt."

Relation of Lead and Zinc Content to Lubrication

Discussing the various bearing metal bronzes according to their accepted trade numbers, the Federal Mogul Corporation has gone into exhaustive detail in developing information pertinent to lubrication. The chart on page 16 is a summary of their opinions, as well as those of other authorities in regard to strength, load-carrying ability and lubrication. It is to be noted that with increase in lead content a bearing metal will function more dependably on reduced lubrication, or under conditions where, for any reason, lubrication may be temporarily interrupted. Lead content also has a direct effect upon ease of cutting and broaching, as well as performance in service under varying pressures and speeds.

The Bureau of Standards has investigated the wearing properties, hardness, structure, notch toughness and resistance to deformation of bearing bronzes with and without zinc.* Their conclusions are of particular interest, viz.:

"Bronzes with less than about 4 per cent tin were considered to be unsuited for general bearing service, since they had low resistance to deformation and wore rapidly in the absence of lubrication."

"Bronzes with less than about 5 per cent lead appeared to be suited only for service where lubrication could be maintained."

"Bronzes containing more than about 5 per cent lead were best able of any of the groups studied to operate for short periods in the absence of lubrication. Bronzes with 15 per cent lead were better in this respect than bronzes with 5 per cent lead, but there were no appreciable advantages apparent in raising the lead above about 15 per cent."

"The addition of 4 per cent zinc to the copper-tin-lead alloys had, in general, a small influence upon the properties of the bronzes studied. With two exceptions, such changes as were observed seemed beneficial rather than detrimental for bearing service since they comprised a tendency toward higher hardness and resistance to deformation under repeated blows, lower friction, and also lower wear in the absence of oil."

"Further developments of methods of test for wear in the presence of lubricants may show that zinc tends to increase the weight losses and duration of the "wearing-in" period of bronze bearings, but since this is also a function of the perfection of fit such effects would be disadvantageous only in certain cases."

Speed a Factor in Choice of Bearing Metal

In regard to choice of bearing metals, certain authorities are of the opinion that for shafts rotating at relatively high peripheral speeds, i.e., in excess of 800 feet per minute, it is usually advisable to use babbitt lining, the bronzes being best adapted to lower speed conditions. There will, of course, be exceptions to this rule and when bronze without babbitt is contem-

*"Bearing Bronzes With and Without Zinc," by H. J. French, Senior Metallurgist, and E. M. Staples, Research Associate, Bureau of Standards. Research Paper No. 68.

plated, factors such as running clearances, means of lubrication, hardness of the shaft should be developed so that the proper type of bronze can be selected to meet the requirements.

The Bunting Brass and Bronze Company has worked out an especially interesting curve, showing the direct relation of speed to load, and method of determining the maximum load at any given speed for a well lubricated bearing. See Figure 3.

APPLICATION OF BEARING METALS

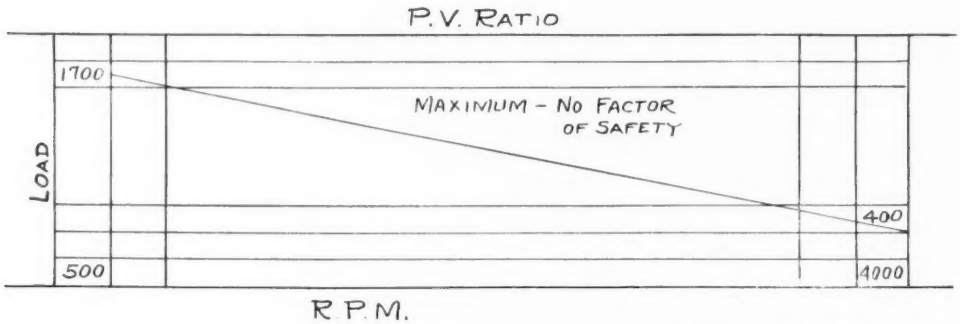
In application of bearing metals to actual service, their handling involves four distinct steps, viz.:

Treatment of the shells,
Preheating of the shells,
Melting of the bearing metal,
Pouring to form the bearing.

off grease or moisture and insure complete contact and equal shrinkage of both bearing and shell as cooling occurs.

Preheating of the bearing shell as well as the journal or mandrel prior to pouring or casting of babbitt or bearing metal also assures of smoother flow of the latter with less tendency for settlement or stratification of the heavier components of the alloy. Normally bearing shells and mandrels should be heated to from 200 to 500 degrees Fahr., depending upon their construction. The heating temperature should always be sufficient to liquify the solder or tin as the case may be.

Should molten metal be poured into a shell which is too low in temperature, blow holes might appear due to gas pockets, and premature freezing might cause the mould to be incompletely filled, and the resultant bearing poorly formed. In subsequent operation a



Courtesy of The Bunting Brass and Bronze Co.

Fig. 3—Chart showing relation of speed to load and method of determining maximum allowable load at any given speed for a well lubricated bearing, based on Bunting bearing testing machine.

Where bronze bearing shells are used certain authorities* suggest that they be cleaned with muriatic acid and tinned with pure block tin rather than solder, unless this latter is definitely known to be a half and half mixture of tin and lead. This procedure is essential to proper adhesion of the bearing metal. After tinning the same authorities feel that the shells should be heated to a sufficient degree to cause the tinning to show signs of sweating.

Steel castings in turn should also be tinned prior to pouring of the bearing metal. The contact surfaces, however, should be machined before tinning to assure of even distribution. On cast iron or malleable shells tinning is a difficult matter, for this reason dove-tails are usually preferred. The bearing metal should be well hammered or peined in a cast iron shell after pouring, leaving a good riser, to allow for shrinkage and compression in hammering.

The mould or shell should be cleaned and preheated while the bearing metal is being heated. The purpose of preheating is to burn

bearing in which this has occurred might be torn loose from the shell, or develop flaking when subjected to the turning force of the rotating shaft or journal. According to other authorities** while such failure may appear to be due to wiping, it is actually due to bond failure. Furthermore, flexing of the unfused lining causes fatigue failure.

Lubrication would, of course, influence any such behavior of a bearing. Even a relatively poor bearing may give passable service if properly lubricated. On the other hand, the most perfectly formed metallic bearing will fail if lubrication ceases for any extensive period. For this reason, where there may be any doubt as to the suitability of the bearing metal or the manner of its casting, most careful attention should be given to keeping the lubricating system free, in order that perfect circulation of oil may be assured.

Melting Procedure

Melting of bearing metals should be carried

*Magnolia Metal Bearing Book.

**The Bunting Brass and Bronze Co.

out in a clean ladle, heating to pouring temperature as quickly and uniformly as possible. As soon as the metal has been brought to the molten state it should be poured and cast, without any unnecessary delay. Powdered rosin is often recommended both as a flux and to prevent spattering of metal in pouring, which might occur should there be any moisture present in the shell, or in event of the latter being too cold. Overheating of certain types of bearing metal is injurious, just as is prolonged heating, due to possibility of oxidation or alteration of the alloy.

The copper content of the tin base bearing metals influences the melting point; the pouring temperature should therefore always be safely above this latter. As a rule, the higher the copper content the higher should be the pouring temperature. Furthermore, due to the fact that copper has a tendency to segregate, a thorough stirring and skimming of dross prior to pouring is advisable. Stirring should be carried out with an upward motion to prevent formation of unmixed layers of the component metals which constitute the alloy. This may be especially liable to occur at the bottom of the container. It may also occur if the temperature is allowed to drop sufficiently to cause a portion of the alloy to solidify. Segregation is often due to difference in specific gravities of the metals used in the alloy. Any bearing formed from stratified metal may give subsequent trouble, for the base metal especially, if it is tin or lead, will have no appreciable sustaining ability. Particular care must be taken with lead base metals, for the lower part of a bearing formed from improperly mixed babbitt may be so soft as to tend to squash out. In turn, scoring of the shaft, or journal, or overheating and cracking of the bearing may develop if an excess of the more brittle constituents such as antimony is concentrated at the contact surface.

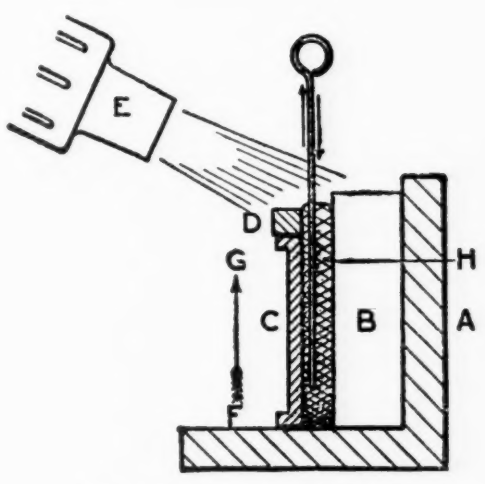
Under-heating of certain types of metals will lead to formation of coarse granular castings. Overheating, in turn, may cause partial oxidation as already stated. In service, bearings cast from over-heated metal may shrink abnormally, due to alteration of the alloy structure. Softening and reduction in bearing or supporting ability may also prevail. A dirty or tarnished appearance on the surface of the bearing is often indication that the metal has been over-heated prior to pouring.

For the above reasons most careful attention should be given to regulation of bearing metal temperatures. Use of a pyrometer and careful following of pouring instructions as suggested by bearing metal manufacturers is highly advisable. Where a pyrometer is not available a reliable method of ascertaining when a lead base metal, in particular, is right for pouring is to stir with a white pine stick. When it chars the temperature of the metal is approximately correct for pouring. With tin base metals, on the other hand, or alloys containing a considerable amount of copper, the liquidation point will be higher. With such metals, in the absence of pyrometer, the stirring stick must actually burn before the metal is hot enough to be poured and cast into a dependable bearing.

Pouring Procedure

Having brought the bearing metal, shell and mandrel to the requisite temperatures to assure of positive formation of a suitable casting, the next step is to pour or cast the actual bearing. The procedure to follow is clearly outlined by the Magnolia Metal Company, viz.:

"A ladle of the self-skimming type, that is with welded or riveted sheet-iron bridge . . . is preferable for pouring, as it permits the size of the metal stream to be predetermined, prevents splashing and keeps slag at the top of the ladle from getting into the mould. If a plain ladle is used, the lip should be kept clean and free from burrs or other surface irregularities that would interfere with a smooth solid stream, and scum should be kept from entering the mould. This ladle should be held close to the pouring hole to avoid air bubbles or chilling the metal.



Courtesy of The Hoyt Metal Company of Great Britain, Ltd.

Fig. 4—Showing method of applying heat to bearing metal in casting to insure smoothness and avoid blow-holes. A is an angle plate forming the main part of the jig; B is the mandrel or core; C the bearing and H the white metal between mandrel and bearing shell; D is a half ring.

"The metal should flow steadily and in a way to avoid splashing and pocketing of air. A trifle more metal should be added after the mould is apparently full, in order that any impurities tending to remain after skimming

will overflow. The babbitt will shrink a little in cooling, and by continuing to pour after cooling has started, shrinkage in the bottom of the mould will be at least partially compensated.

DATA REQUIRED FOR CORRECT BEARING CALCULATIONS*

LOAD	A—Constant B—Intermittent Shock
R. P. M.	Direction
ACTION OF PART	Rotating B—Oscillating C—Sliding D—Thrust E—Rotation of shaft or bearing
SHAFT	A—Material B—Diameter C—Hardness D—Finish
MANUFACTURING PROCEDURE	A—How housing is finished B—How bearing is C—How rubbing surface is finished
FINISH OF BEARING SURFACE.	
CLEARANCE BETWEEN SHAFT AND BEARING.	
LUBRICATION	A—Constant B—Interrupted C—Kind of Lubricant D—Grooving
SURROUNDING CONDITIONS	A—Heat B—Dirt C—Possible damage by oil leaks D—Acids
PROJECTED AREA NEEDED TO CARRY LOAD WITH CORRECT MATERIAL.	
WALL THICKNESS NEEDED TO PREVENT POUNDING OUT OF BEARING.	
WEAR RESISTANCE.	
MATERIAL NEEDED FOR APPLICATION.	
CONCLUSION.	

* The Bunting Brass and Bronze Co.

"Best results are obtained by pouring with the shells in a vertical position and directing the stream against the mandrel. Irregular shape of the mandrel may make this impossible, in which instance, the mould may be inclined for pouring at the most convenient point. Split shells poured singly at an angle should face downward. They are also sometimes placed in horizontal position on a surface plate, with convex side up over the mandrel, and the babbitt poured through holes put in the casting for that purpose.

"Each liner should be poured complete at one operation, so that on large work, a pot of liberal size is desirable. If the ladle is too small, a second ladle should be on hand and ready as soon as the first is empty, in order that there will be no break in the babbitt.

"The kettle of molten metal and the bearing should be kept close together, as carrying a ladle of molten metal any distance is bad practice. Aside from possible danger of spilling, the ladle contents may cool enough to impair smooth flow into the mould."

Further advice in regard to obtaining smooth castings is given by the Hoyt Metal Company, of Great Britain, Limited, viz.:

"To ensure smooth castings and to avoid blowholes, immediately the bearing is full, dip a piece of clean steel wire in and out all round, lightly and without force (it should be possible to reach the bottom), and at the same time prevent the metal at the top from setting by means of the blowpipe E (Fig. 4). The metal at the bottom F will solidify first, and will gradually rise in the direction of the arrow to G. Finally, the metal will be solid up to the top, which can be finished off clean and smooth by means of the blowpipe. During this operation of venting (which takes, say, two or more minutes, according to size of bearing), the metal may sink down from the top; if it does, a little more should be poured on. Cool the bottom of the bearing with cold air from the blowpipe as quickly as possible. If cold air is not available, a wet sponge or cloth may be pressed against the lower part of the bearing, care being taken that damp or water does not reach the molten white metal inside the bearing.

"In Fig. 5 a half-ring is laid on the top of the shell to allow the metal to be cast higher than the bearing itself, so that the shrinkage on cooling shall take place in the metal to be cut off, and not in the metal to remain in the bearing.

"It is desirable that all bearings be filled in an upright position, which enables better control of cooling, permits of venting, and lessens the liability to blowholes and shrinks."

OIL GROOVE DESIGN

Continuous and effective lubrication of any sleeve type bearing is assisted by providing means to assure distribution of lubricant to the entire bearing surface, and especially to that area which is subjected to maximum pressure.

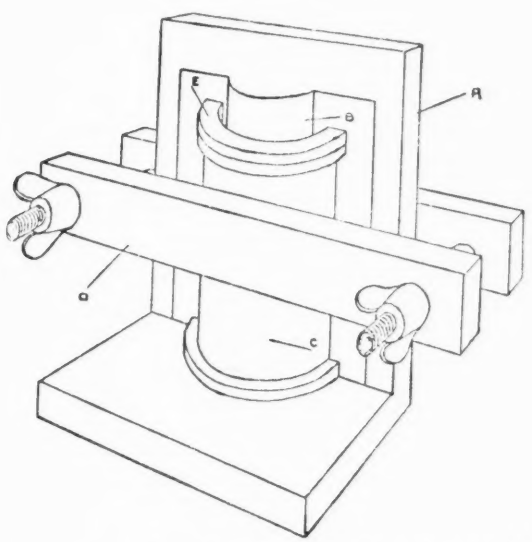
Oil grooves cut in the low pressure surfaces of the bearing aid materially in developing complete circulation of oil and maintenance of a sufficiently protective film at the high pressure area, providing the lubricator or means of initial delivery of oil is adapted to the constructional and operating conditions.

Oil grooves may be defined as a series of depressions in a bearing surface connected or

so located with respect to each other and the point of maximum bearing pressure as to insure not only complete and ready distribution of lubricant throughout the bearing clearance space, but also a pathway for collection and subsequent flushing out (through a suitable outlet) of any abrasive or other foreign matter which might gain entry to impair lubrication and lead to increase in friction and power consumption. They are regarded as essential on most bearing surfaces which must carry shafting or journals subjected to rotary motion, or reciprocating parts such as engine crossheads which involve sliding motion. There are, of course, certain exceptions, especially where the maximum of bearing area must be employed, where rotational speeds may be comparatively low, and unit pressures per square inch are fairly high, or under high speeds such as in aircraft engine service.

Effect on Power Consumption

Many designers and builders of industrial machinery often attach too little importance to oil grooving, assuming that if one or two holes are drilled in a bearing cap to provide for connection to some means of individual or collective lubrication the natural rotational effect of the journal, shaft or pin, or the sliding



Courtesy of The Hoyt Metal Co. of Great Britain, Ltd.

Fig. 5—Showing manner of constructing a jig suitable for small half bearings. A is an angle plate; B a half mandrel and C the bearing shell, held in position by a clamp, D. A half ring, E, is laid on top of the shell, to allow the white metal to be built up over the flange at the top.

motion of the crosshead, for example, will draw in sufficient oil to develop the necessary film of lubrication. This may hold true where bearing edges or the point of entry of the lubricant to the bearing are chamfered or cut away to aid in distribution of lubricant. On the other hand, such construction may lead to abnormal power consumption.

Actual testing in comparison with a properly grooved bearing to note the amount of power consumed and the extent to which operating temperatures may be in excess of normal, according to the location and type of machinery involved, will normally convince one of the importance of grooving as an adjunct to more efficient operation. To leave the location and arrangement of grooving to shop employees who have to deal with babbitting of bearings, for example, may, therefore, be a dangerous procedure unless they are furnished with definite working details as to dimensions and location of such grooves with respect to direction of rotation and pressure areas.

With an understanding of the benefits to be derived from grooving of bearings, discussion of how oil grooves function in service will be of interest. Normally they provide an initial receptacle for the receiving of lubricant as it passes into the bearing from the lubricator, thus serving as a means for distributing lubrication length-wise along the bearing, so that as the moving surface of the rotating or sliding element passes the grooves or chamfers it will take up an adequate protective film of lubricant.

Where properly designed, grooves also aid in retaining lubricant within the bearing clearance space and prevent abnormal leakage via the bearing ends. By suitably designing a system of grooving provision can be made for circulation of oil alternately from the center of the bearing to the outer ends and back again. How intricate such a layout would have to be would depend primarily upon the means of initial lubrication. Where sight feed or drip lubrication is involved, or in other words periodic lubrication with just about the right amount of oil to maintain an adequate lubricating film, grooving will play a more important part than where flood lubrication is employed.

Features in Design

Any plan for oil grooving must be simple as well as practicable. Abnormally intricate layouts will be of no material value.

Where manufacturers of machinery or bearings have given study to the requirements of their specific equipment, their systems of grooving may be regarded as satisfactory, even though all may not be the same from the viewpoint of arrangement. The all-important factor is to attain such effective lubrication that friction and power consumption will be reduced to a minimum. The means of attainment is more or less secondary, provided, of course, that available bearing area is not seriously reduced.

Grooving should be confined to those parts of the bearing which carry the least load. In a two-part bearing this will mean that only the top bearing normally should be grooved. In a four-part bearing, the segments to consider would depend upon the direction of rotation of the journal or shaft. Normally the bottom part should be plain or ungrooved.

Theory has proved that the oil must flow from a low pressure area to a zone of higher pressure. Should this latter be grooved to any extent there may be the possibility of oil being carried from the bearing, the lubricating film impaired, waste increased, and the development of abnormal wear. Oil leakage at the bearing ends with increase in temperature can often be regarded as indication of faulty grooving adjacent to the high pressure area.

Where flood lubrication is involved, the arrangement of oil grooving in a bearing will not be so important, nor so contingent upon the direction of rotation as where periodic or drip lubrication is employed. On the other hand, this should not be regarded as a reason for grooving a bottom bearing in, let us say, a ring or pressure oiled system, however, for lubrication would normally not be improved, and the effective bearing area in the high pressure zone would only be reduced. Direction of rotation must always be considered more carefully in a drip lubricated bearing, for flow of oil through the oil grooves may be materially affected. Oil flow should be directed toward the center of the bearing, not toward the ends.

Bearing authorities are in agreement to the effect that oil grooves should never be extended too close to the ends of the bearing surfaces, for in such event oil will tend to escape from the clearance space to be lost by drip or leakage. As a general rule it will be well to keep such grooves a certain distance in from the bearing ends, according to the size of the bearing and journal involved.

The following table will be of interest in this regard:

Bearing Bore	*Distance of grooves from either end*
1¾″ or less	¼″ min.
1¾″-2″	⅜″ min.
2″-6″	½″ min.
Above 6″	1″ min.

FORMATION OF GROOVES

Cutting or formation of oil grooves should be done with considerable care in order that they may conform as nearly as possible to the calculated dimensions, and the intended location with respect to curvature and the ends of the bearing.

The possibility of clogging will be increased should the depth be uneven or the edges wavering. As a general rule, more or less contaminating solid foreign matter, such as dust and dirt or metallic particles, will be present in almost any oil after service for any length of time. Furthermore, if higher operating temperatures prevail, certain types of lubricants may have a tendency to break down to gummy or carbonaceous deposits. The more or less inert character of all such non-lubricating matter will render it sluggish in circulation. High spots in an oil groove may tend to act as a dam, or uneven edges as a deterrent to perfect circulation. This may ultimately result in collection of deposits at these points, with consequent retarding of lubrication. If this occurs to excess maintenance of adequate lubrication over the pressure area may be impaired.

Hand-cutting is very frequently preferred by machinists in the forming of oil grooves, although it is perfectly practicable to machine them. Where the former prevails, there may be more possibility of variation from the calculated dimensions, although the fineness of the work will depend, of course, upon the skill of the mechanic and the care taken in manipulation of cutting tools. Rough surfaces must be guarded against, whatever method may be used for cutting grooves. Not only will rough spots tend to impair free circulation of oil through the grooves, but also heavier foreign matter may be more easily retained at such places. Roughness may be indicative of loose particles of bearing metal. If adjacent to the main surface of the bearing, the occurrence of metal-to-metal contact might lead to breaking or chipping off of certain of these metallic particles, to cause contamination of the lubricant and possible scoring of the shaft or bearing surfaces should the copper or antimony content be relatively high.

Courtesy of A. W. Cadman Manufacturing Co.

Fig. 6—Showing formation of an oil film. View to left indicates relative position of film as rotation commences. Other figures show in succession how wedge of oil forces the shaft over, to raise it horizontally and insure complete separation from the bearing.

Calculation of Dimensions

The general dimensions of an oil groove in a sleeve-type bearing will depend upon the diameter of the shaft or journal which is to be carried therein.

Width can be figured by multiplying the

diameter in inches by 0.01 and adding 0.10 of an inch as more or less of a factor of safety.

For *depth* one-half of the calculated width as determined above can then be assumed as the proper figure for the groove in question.

Typical Examples

It will be of interest in this regard to work out some examples based on shafting or pins of different diameter, viz.:

1—Given a crank shaft of 30 inches diameter:
$(30 \times .01) + 0.1 = 0.4$ inches—width
$0.4 \times \frac{1}{2} = 0.2$ inches—depth
In other words, the above groove would be say $\frac{3}{8}$ of an inch wide by $\frac{3}{16}$ of an inch deep.

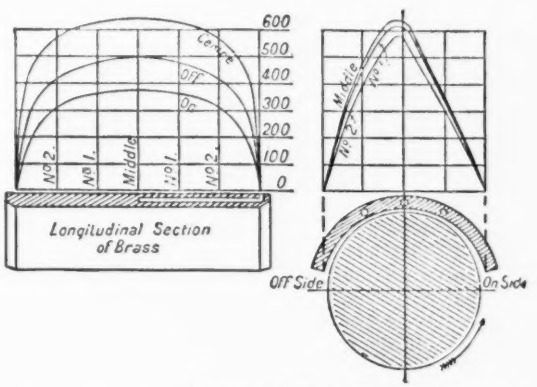
2—Given a shaft of 12 inches diameter:
$(12 \times .01) + 0.1 = 0.22$ inches—width
$0.22 \times \frac{1}{2} = 0.11$ inches—depth
This would correspond approximately to $\frac{1}{4}$ of an inch wide by $\frac{1}{8}$ of an inch deep.

3—For a smaller bearing, say a pin of $1\frac{3}{4}$ inches diameter, it will be well to assume this latter as 2 inches as an added factor of safety.
As a result:
$(2 \times .01) + 0.1 = 0.12$ inches—width
$0.12 \times \frac{1}{2} = 0.06$ inches—depth
This would result in a groove $\frac{1}{8}$ of an inch wide by $\frac{1}{16}$ of an inch deep.

The thickness of bearing metal should always be ample to allow for the above calculated depths of grooves without danger of cutting through to the bearing shell. As a rule, however, it will be safest to note just how much thickness of bearing metal is actually present before grooves are cut or bearing edges chamfered or beveled. One should always remember, when planning a system of oil grooving and calculating the dimensions, that available bearing area is reduced by oil grooves. Under normal conditions where such grooves are cut in the bearing cap or low pressure area, actual metal-to-metal contact may not be so apt to occur as over the high pressure area. And yet, pressure exists throughout the bearing; therefore, even the low pressure area should not be reduced any more than necessary by excessive grooving, too great width, or extensive chamfering.

High Speed Operations

In construction of sleeve-type bearings for high speed service, where flood lubrication under pressure is employed, oil grooves are frequently considered to be less effective than where speeds are lower. Here pumping action within the bearing, plus the constant pressure under which the oil is applied, aids in effectively maintaining protective lubrication. Under such conditions the presence of oil grooves might easily become a detriment instead of a benefit. This has been given particular study in aircraft engine design, where bearings are comparatively small, with the result that today practice of grooving is discouraged by certain builders.



Courtesy of A. W. Cadman Manufacturing Co.

Fig. 7—Tower's chart showing distribution of pressures in the oil film.

In other industries where designers of high speed installations continue to groove the low pressure side of their bearings, as for example in steam turbine service, tendency is to employ a wider and more shallow groove than the calculations heretofore cited would require. This method of grooving results in the formation of bearing strips in the low pressure or upper half of the bearing.

With this type of construction the oil film is but slightly thicker at the grooves than at the bearing strips. Consequently bearing clearances can be reduced, to insure of minimum vibration, yet maintenance of a positive lubricating film.

Sharp Edges Must be Eliminated

Where sharp edges exist at any part of a bearing surface there will be a tendency for oil to be scraped from the smooth surface of the moving element, instead of being uniformly distributed within the clearance space between the rubbing surfaces. This will interfere with the pumping action which is brought about by the rotating or sliding element, according to the type of installation. Pumping action aids in the maintenance of a suitable oil film within the clearance space of a plain or sleeve-type bearing. Effective lubrication is also assisted by providing for passage of oil from the low pressure to the high pressure area. As a general rule this will mean from the upper to the lower part of the bearing.

For this reason oil holes are usually located in the top part or cap of the average bearing,

when lubrication is to be maintained from an external source. In addition, by suitable grooving of the top part or low pressure area of such bearings, especially in industrial machinery, more positive delivery of sufficient oil to the point of entry of the high pressure area will be assured.

The possibility of the oil film being scraped off or otherwise impaired, however, must be eliminated. Sharp edges around oil holes or along grooves must be rounded off to a convex surface. Furthermore, bearing edges should be chamfered or cut to a more or less concave surface so that when the respective shells are in place an oil groove will be formed, of about the same depth and width as the grooves in the low pressure area of the bearing.

In this way flowing or wedging of oil from the grooves or oil holes into the clearance space between the rubbing surfaces can be more readily accomplished by the maintenance of a continuous Vee-shape in the oil film at such points.

A bearing edge should never be chamfered or beveled over its entire length for this would subsequently lead to oil draining off to perhaps be wasted. If the cut is terminated a distance of from ¼ inch to 1 inch from the end of the bearing, according to the diameter of shaft to be carried, possibility of appreciable loss of oil will be reduced.

In service the chamfered or beveled space will serve as more or less of an oil reservoir, just as will an oil groove, when the shaft or journal is idle. It is very important that such a condition exist in larger bearings which must carry heavy shafts, operating at low or moderate speeds, for when idle for any length of time the weight of the shaft will tend to squeeze the oil film out from the bottom or high pressure part of the bearing, to result in actual metallic contact. Subsequently, on starting, unless oil is immediately delivered to such an area, friction, wear, and possible scoring may develop. If the oil grooves and chamfers are more or less filled with oil, however, the drawing-in or pumping action of the shaft as it begins to rotate will result in immediate formation of at least a partial oil film. As speed is gathered this latter will continue to improve, assuming that sufficient fresh oil is delivered by the lubricating system.

PRESSURE DISTRIBUTION IN THE OIL FILM

As a shaft or journal rotates in its bearing, pressure is developed. When lubrication is adequate this pressure is distributed through the oil film, so that the rotating element is supported by this film. The load, however, will not be evenly distributed and, therefore, pressure distribution will not be uniform throughout the bearing. In normal operation there will be a high and low pressure area, the relative location being dependent upon the direction of rotation and the turning speed of the journal. Location of the pressure areas in a bearing is important, especially where oil grooving is to be planned. *Cadman has discussed the theory involved in a most practical way, viz.:

"The process of formation of the oil film can be demonstrated by an examination of Figure No. 6, which exaggerate the relative diameters of shaft and bearing for the sake of clearness. The actual thickness of the oil film under average conditions is .0002 inch.

"When the journal is at rest it lies at the bottom of the bearing and, as the oiling device is generally inoperative, the surfaces are nearly dry. As rotation commences the journal rolls upward on the left hand, or "on," side of the bearing, and if the velocity is very low it will continue to rotate in this position and no oil film will be formed.

"Immediately, however, the velocity reaches a value of even 10 feet per minute oil is drawn into the bearing by the journal and forms a wedge. This wedge of oil forces the shaft over to the "off" side, raises it in the horizontal direction, and at the same time completely separates it from the bearing.

"As the velocity increases, the thickness of the oil film becomes more uniform and the center of the shaft approaches more closely to the center of the bearing.

"If the load be now increased, as the speed is kept constant, the journal tends to approach a point on the bearing about 40 degrees from the vertical, and if it be further increased the oil film will be ruptured.

"It should be noted that the pressure in the oil film is at a maximum at a point just ahead of the point of nearest approach of journal and bearing. The point of minimum pressure is just beyond the point of nearest contact and a vacuum of as much as 30 inches has been found at this point.

"Figure 7 shows the distribution of pressure in the oil film as determined in the famous experiment of Beauchamp Tower. In this experiment a load of 8008 pounds was applied to a bearing with an effective surface of 23.52 square inches giving a pressure of 340 pounds per square inch. Pressure gages were inserted in the bearing at 15 points and these indicated the pressures shown in the chart at a speed of 156 feet per minute."

*Bearings and Bearing Metals. Engineering Bulletin M2. A. W. Cadman Mfg. Co.

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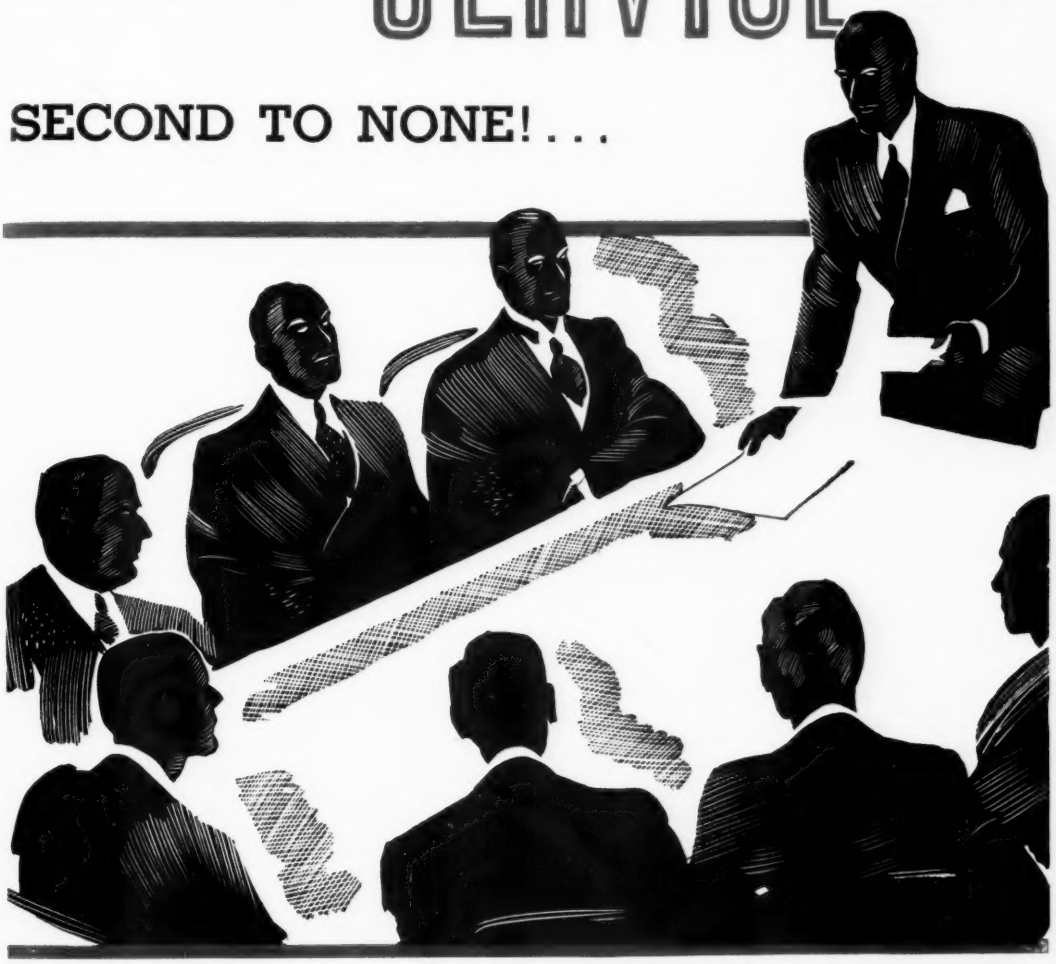

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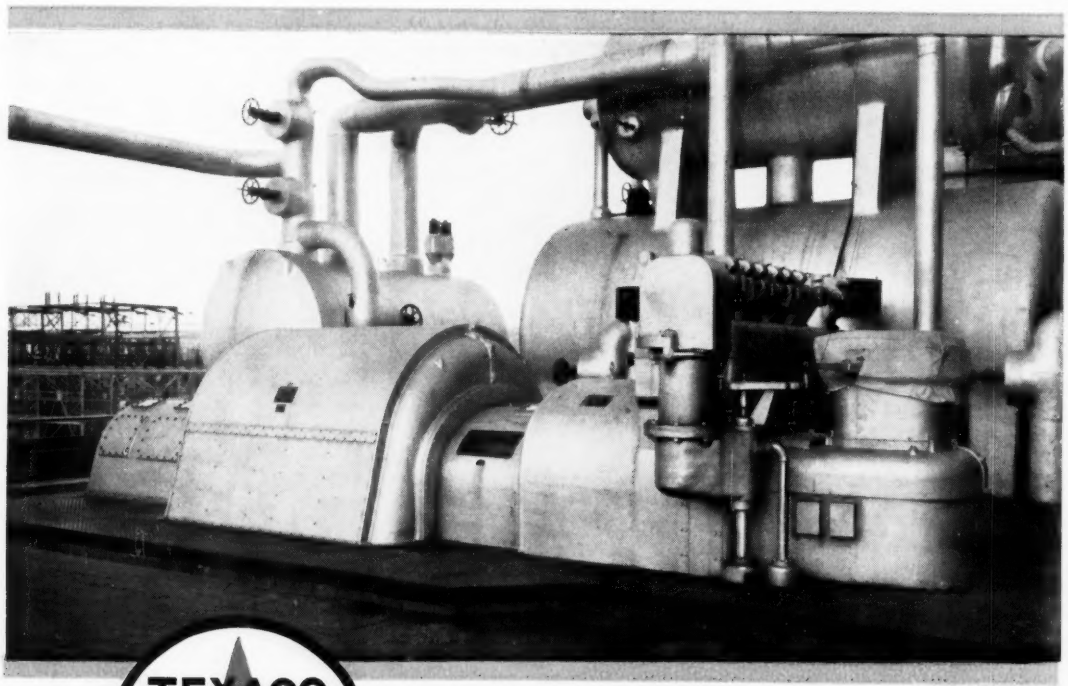

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